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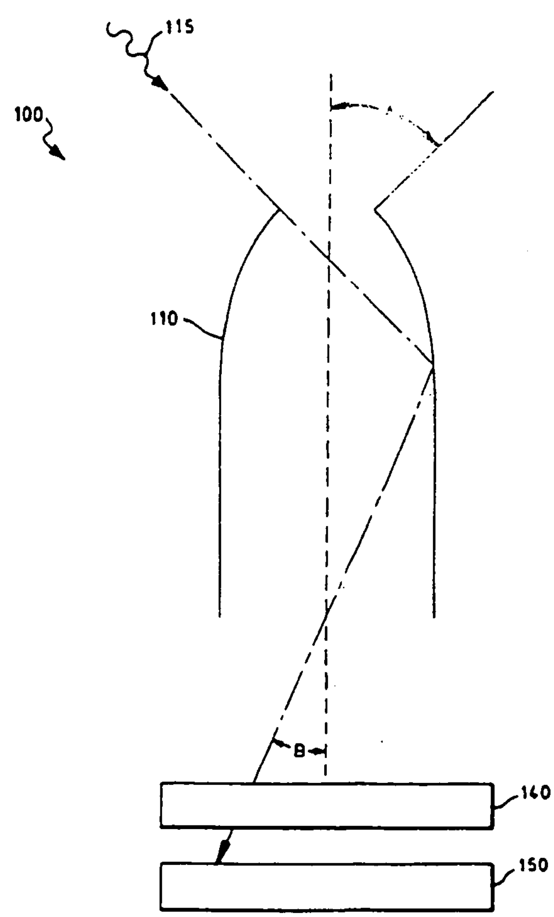
(54) Title: WIDE ANGLE, NARROW BAND OPTICAL FILTER

(57) Abstract

The object of the invention is to provide an optical filtering system which can utilize wide angle optics and still maintain a very narrow pass band. A filtering system (100) is disclosed for receiving and bandpass filtering free space optical signals. The filtering system (100) includes a compound parabolic concentrator (110) with a small aperture for accepting the free space optical signals (115) and a larger aperture whereby the optical signal (115) exits. The compound parabolic concentrator (110) has a reflective coating on the inner surface to reflect incident optical signals (115) to produce a substantially collimated signal beam. The collimated signal is further passed through a narrow, bandpass filter (140) before detection by a photodetector device (150). In an alternative embodiment, a compound hyperbolic concentrator (310) is utilized to reflect the incident optical signals and produce a substantially collimated signal beam.



WIDE ANGLE, NARROW BAND OPTICAL FILTER

Technical Field

The instant invention relates generally to optical filters and more particularly to apparatus which can be used to build optical systems with very narrow band transmission.

Background Art

Often it is desirable to block light or any other optical band radiation from reaching a detector with the exception of radiation within a specific wavelength band. Narrow band optical systems have been developed for a wide variety of applications for many years. The usual objective is to isolate an optical signal of a specific wavelength in the presence of a large flux of noise i.e. optical radiation at other wavelengths. A better signal to noise ratio can be derived from the detector if the signal is within a narrow band of the optical spectrum. Noise is caused by background light outside the band of the signal and such filters typically find use in wireless communication applications as described by Barry, et al. in "High-Speed Nondirective Optic Communication for Wireless Networks", IEEE Network Magazine, November 1991.

In conventional filtering systems, the absorption of light at specific wavelengths is sometimes used as a means of filtering. However such filters are usually not capable of isolating a narrow passband, and they tend to be lossy at the desired band.

In a further approach, filters composed of layers of thin dielectric films consisting of materials with widely differing refractive indices have been utilized. Such filters are known as interference filters and are capable of isolating quite narrow passbands with relatively high transmission at the desired band. Interference filters,

however, have the characteristic that the passband shifts as the angle the light ray makes with respect to the surface of the filter varies. This characteristic is a disadvantage in filtered optical systems which require wide angle reception again as described in Barry, et al., supra.

A filtering system which provides for wide angle reception is described by Martin and Fohl in U.S. Patent 5,124,859. Although this filter is a clear advance over the prior art, it can only operate at wavelengths for which suitable atomic transitions exist.

It is thus desirable to provide an optical filtering system that has a wide angle of acceptance but maintains the narrow passband of a interference filter normal to a well collimated beam. It is further desirable that such a filtering system be amenable to a simple and compact implementation.

Disclosure of the Invention

The above and other objects and advantages are achieved in one aspect of the invention using a compound parabolic concentrator for reception of free space optical signals preferably in the infrared band of the electromagnetic spectrum. The compound parabolic concentrator has a first aperture for accepting the free space optical signals. The angle of acceptance of the free space optical signals is defined by this aperture. The received optical signals pass through the compound parabolic concentrator causing them to be substantially collimated. The optical signals exit the compound parabolic concentrator at a second aperture of the device which is larger than the first before they are input to an interference filter for bandpass filtering of the signals. The filtered signal may be concentrated using a second compound parabolic concentrator before being presented to a photodetector for converting the optical signal to an electrical signal.

Other types of filters can be based on holographs or gratings, but these are not as efficient in that they lose resolution if the angle of light varies over a wide angle.

In another embodiment of the invention, a hyperbolic concentrator is utilized for receiving and collimating the free space optical signal.

Brief Description of the Drawings

FIG. 1 is a cross sectional view of a filter system utilized in receiving free space optical signals in accordance with one embodiment of the instant invention.

FIG. 2 is a graph of a transmission-angle curve for a compound parabolic concentrator.

FIG. 3 is a cross sectional view of a filter system utilized in receiving free space optical signals in accordance with one embodiment of the instant invention and using a second compound parabolic concentrator for concentrating the input signal to a photodetector.

Best Mode for Carrying Out the Invention

One embodiment of the invention is depicted in FIG. 1 which is a cross section of the instant filtering system 100 for receiving free space optical signals, preferably in the infrared band of the electromagnetic spectrum. However, other optical signals for example signals in the the visible and ultraviolet spectrum are within the scope of the invention. In this embodiment radiation, both the signal and background noise enters the device as rays through the small end of a compound parabolic concentrator 110. A compound parabolic concentrator consists of a reflective surface defined by sweeping a parabola around a line or axis in space. Similarly, a compound hyperbolic concentrator is defined by sweeping a hyperbola around a line or axis in space. The surfaces so defined have a

small aperture for accepting the free space optical signal and a larger aperture for the exiting signal which has been substantially collimated by the geometry of the device. The details of the geometry of these concentrators and other types which use combinations of refraction and reflection are given in <u>High Collection Nonimaging Optics</u> by Welford and Winston. The essential feature of all these devices is that they exchange decreased angular spread of the beam for enlarged beam cross section. Used in the opposite sense these devices exchange smaller beam size for larger spread angles - hence the term concentrators.

As shown in FIG. 1, an input optical signal 115 enters the compound parabolic concentrator through the small aperture and is reflected off the internal side walls of the device. As a result of the reflection of the optical signal 115, the signal exits the compound parabolic concentrator at the large aperture substantially collimated before passing to photodetector 150. For a concentrator with a small aperture of area H for receiving a free space optical signal at a maximum angle A and a large aperture K for exiting the signal at a maximum exit angle of B, the product of H x A is substantially equal to the product of K x B. Optical signal Interference filter 140 is of conventional design, and is known by those skilled in the art.

The behavior of an interference filter 140 as the optical rays enter the filter away from the normal is described in <u>Optical Filters and Coatings</u> by Corion Corporation of Hopkinton, Massachusetts (October 1988). Consequently, an estimate of the effective band pass of the filtering 100 system can be derived. With a very narrow passband for the interference filter 140, the system passband will be given by the shift in transmission wavelength at the maximum angle of the cone of rays, B. The percentage shift in pass wavelength is given by:

$$\text{Percentage wavelength shift} = \frac{100(n_s^2 - \sin^2 B)^{0.5}}{n_s}$$

where n_s is an average value of the index of refraction of the interference filter 140, and B is the angle between the beam and the normal to the plane of the filter. As an example, with the average index as 2.0 and an acceptance angle of 10 degrees, the shift is approximately 0.4 percent. With the pass band of the filter centered at 800 nm, the pass band of the system is approximately 3.2 nm. Accordingly, a filtering system with an arbitrarily wide viewing angle can be shown to have a passband only a few nanometers wide.

FIG. 2 is a transmission-angle curve for a compound parabolic concentrator with an angle of exit of B. In this example an exit angle of sixteen degrees is the maximum exit angle. The compound parabolic concentrator comes close to being an ideal concentrator, and has the advantages of being a very practical design and easy to make for all wavelengths since it depends on reflection rather than refraction.

The above achieves the objects of the invention. However, it does this at the cost of reducing the signal as well as the noise. The signal attenuation can be counteracted by increasing the surface area of the ends of the fibers and the detector. In some applications where there are limits on detector area for example because of frequency response requirements or cost, a second compound parabolic concentrator 310 can be utilized between the interference filter and the detector to concentrate the optical rays on photodetector 150 as shown in FIG. 3. The second compound parabolic concentrator is used in a configuration which is opposite the first compound parabolic concentrator. The rays from filter 140 enter the compound parabolic concentrator 310 substantially

collimated and are focused through reflection off the side walls of the device onto photodetector 150. Concentration increases the angle of the rays relative to the optical axis of the system. The product of this angle and the area through which the bundle of rays flow, called the etendue, is constant. However, the detector typically accepts energy over a wide angle with the spread angle emerging from the filter being small in comparison. Thus even in systems where detector area is a limiting factor on signal level, the instant filtering system allows high rejection of background noise without sacrificing much signal.

While there has been shown and described what is at present considered the preferred embodiment of the invention it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention as defined by the appended claims.

Claims:

1. A filtering system for receiving a free space optical signal separated from background optical noise comprising:

a compound hyperbolic concentrator means having a first aperture of area H for for receiving said optical signal at a maximum angle A and passing said free space optical signal therethrough, exiting at a second aperture of area K with a maximum exit angle of B;

an filter means coupled to said compound parabolic concentrator means for rejecting said background optical noise and transmitting said optical signal exiting from said compound parabolic concentrator means;

a photodetector means for detecting said transmitted optical signal of the filter means.

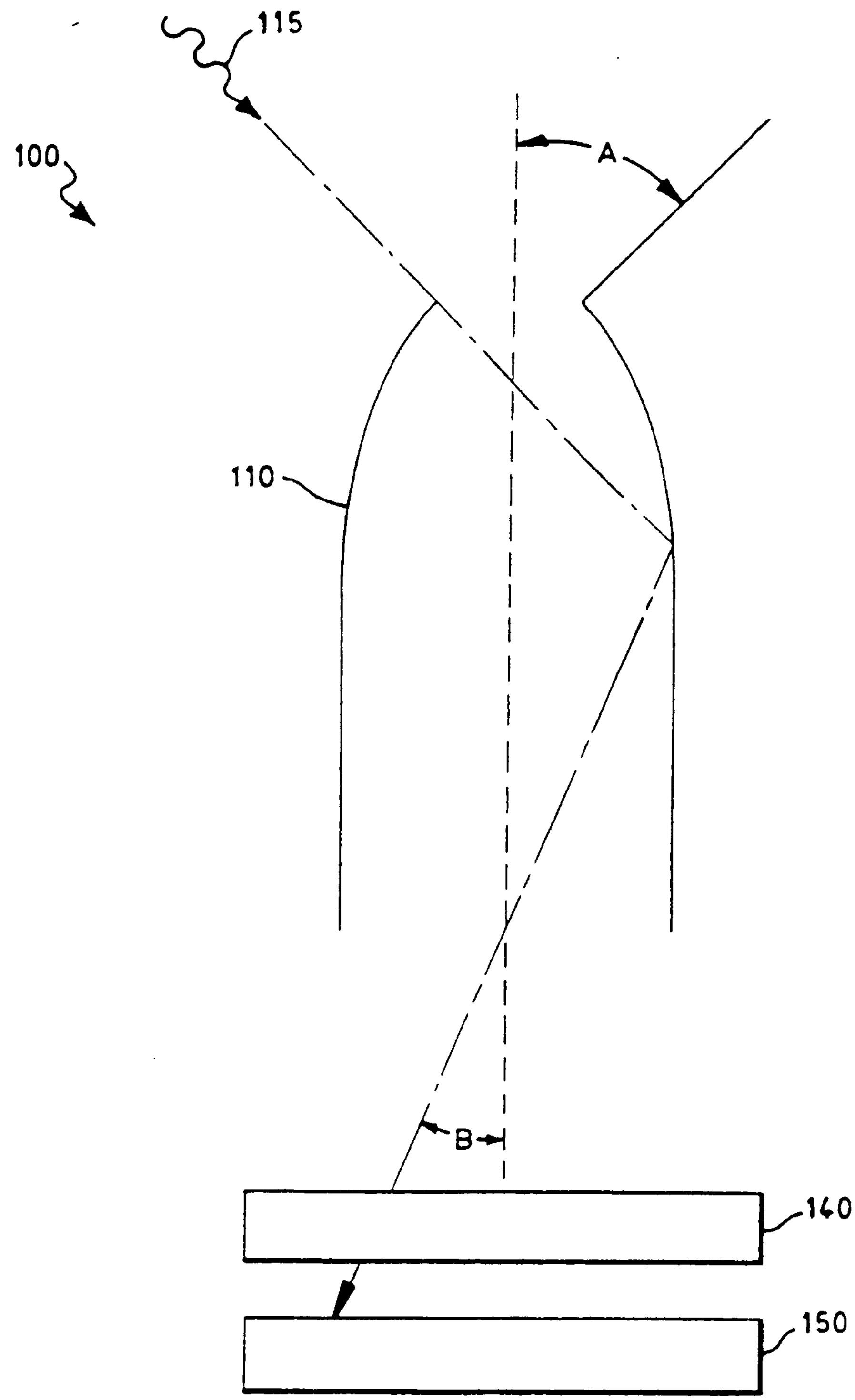


FIG. 1

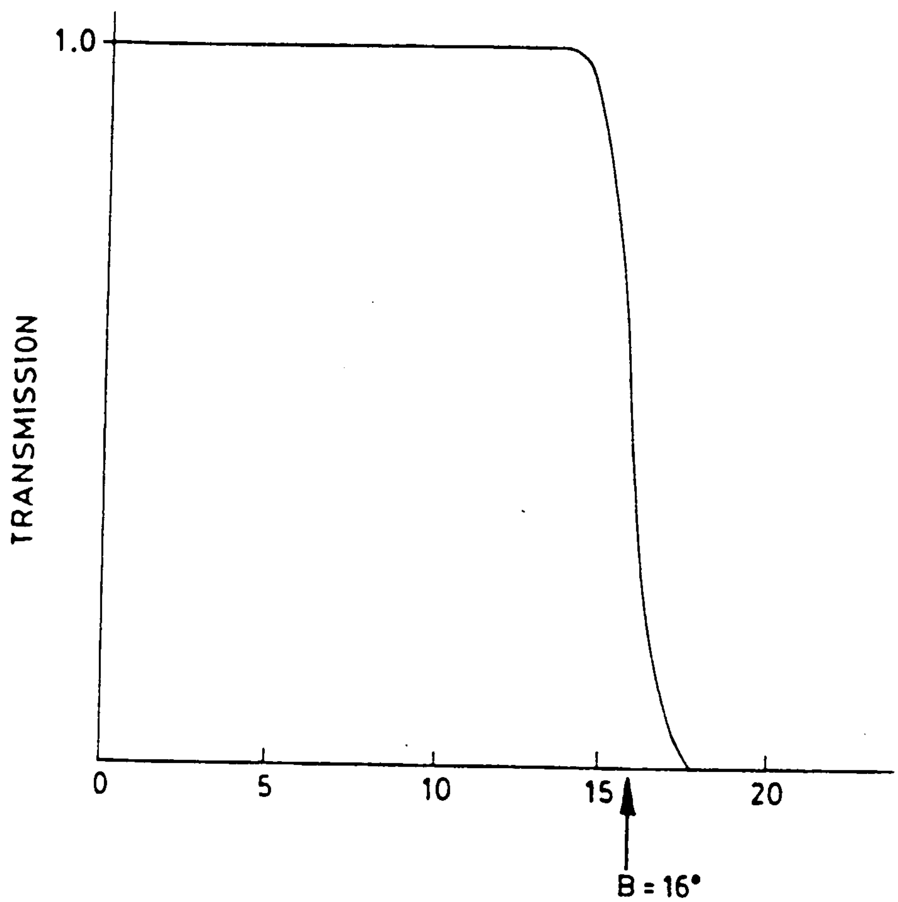


FIG. 2

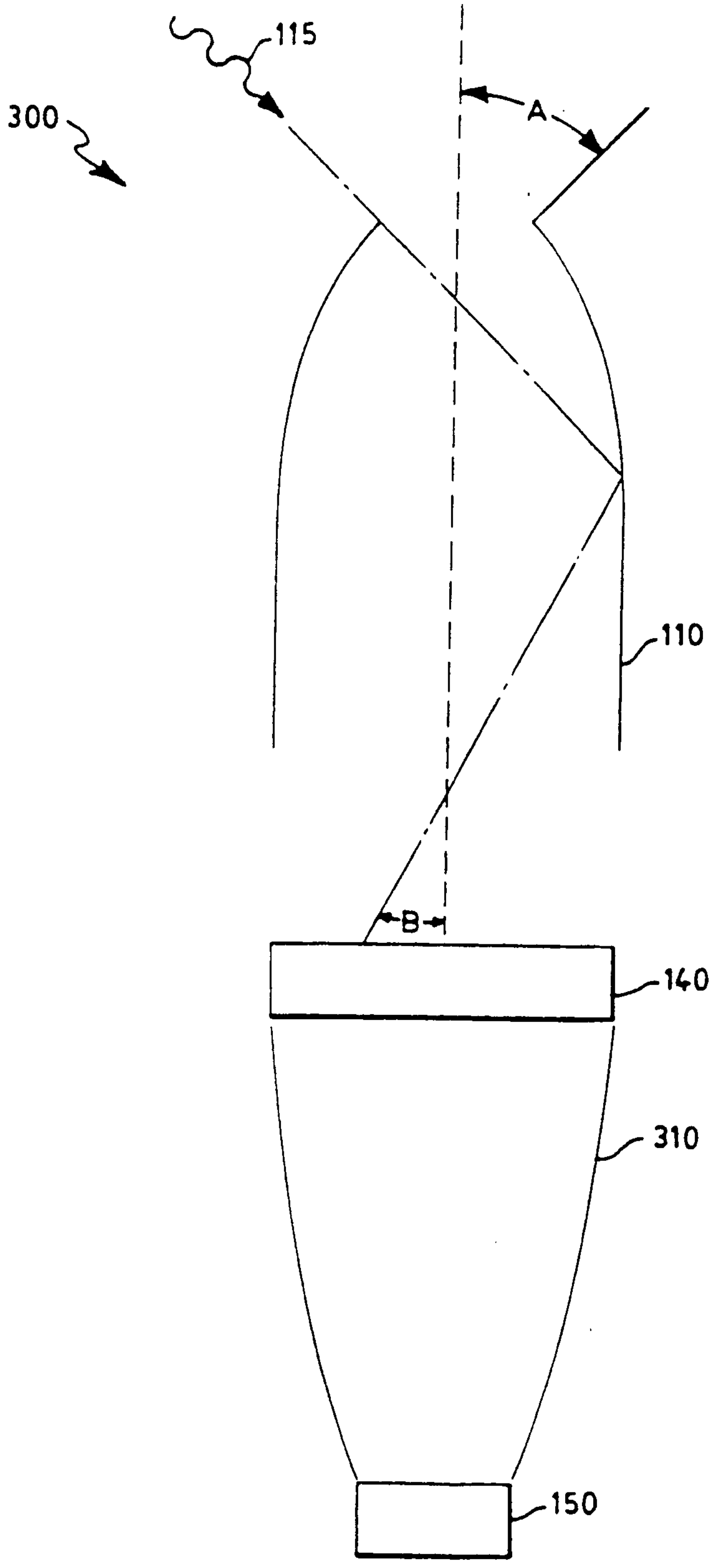


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/12203

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :GO2B 3/02
US CL :359/708, 712, 738

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/708, 712, 738, 709, 739

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Ruda, Mitchell C., "How and when to use a nonimaging concentrator," SPIE, August, 1983, Int. Conf. Hew Imaging concentrators, pp. 51-58, see Figs. 6 and 7.	1

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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18 February 1994	24 FEB 1994

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